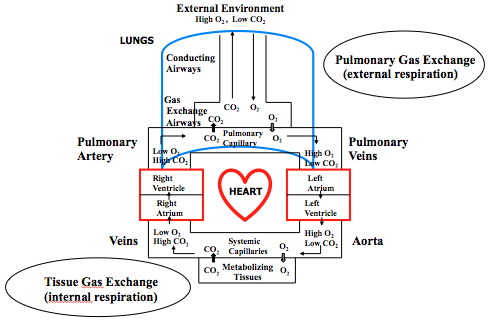
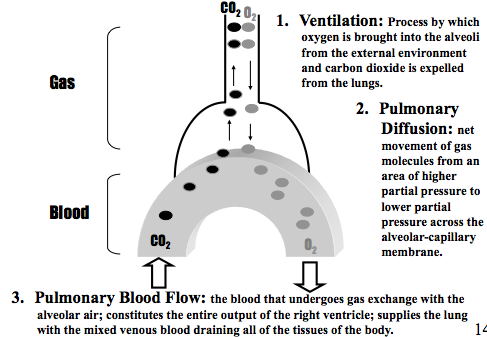
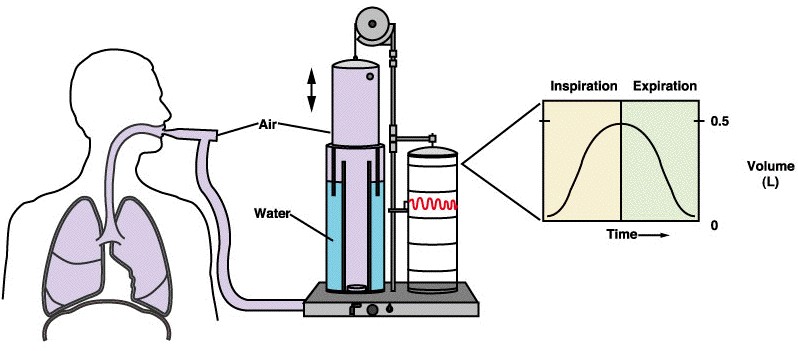
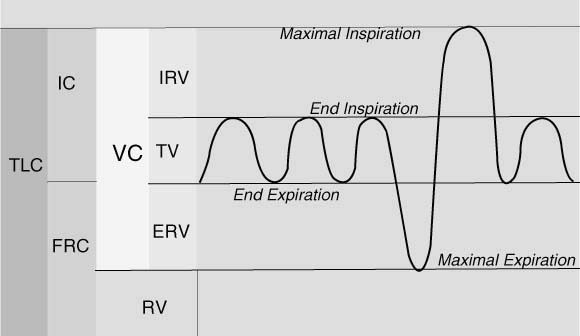
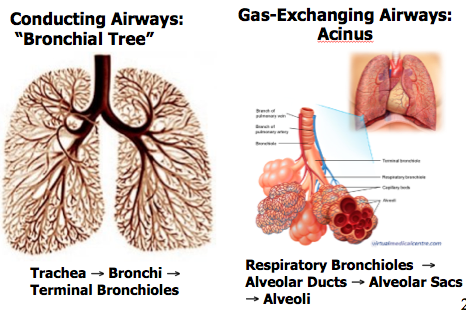
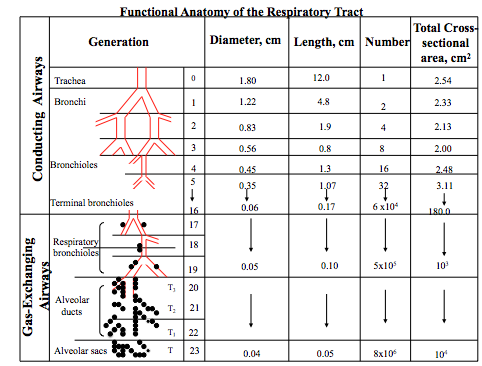
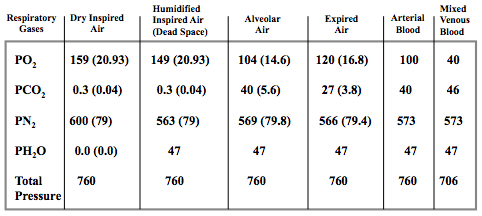
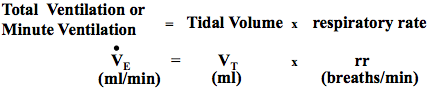
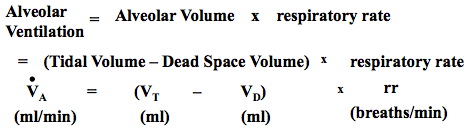
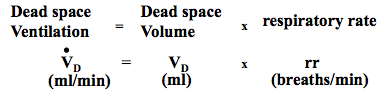
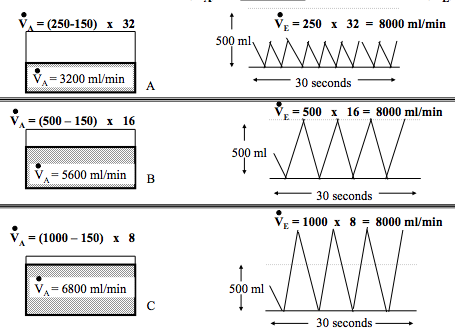
**Pulmonary Gas Exchange I: Ventilation and Lung Volumes**

* Symbols used in Respiratory Physiology
  + *Primary Symbols:*
    - P Partial Pressure of a gas (mm Hg)
    - F Fractional concentration of a gas
    - V Volume of a gas (ml)
    - V (with dot on top) Flow of a gas (ml/min, L/s)
    - Q Volume of blood (ml)
    - Q (with dot on top) Blood flow (ml/min)
    - S Saturation in the blood (%)
    - C Content or concentration of a gas in the blood (ml/100 ml blood)
  + *Secondary Symbols (the subscripts!)*
    - Gas Phase (capital letters)
      * I Inspired air
      * E Expired air
      * A Alveolar air
      * T Tidal air
      * D Dead space air
    - Blood Phase (lower case letters)
      * a Arterial blood
      * v Venous blood
      * v Mixed venous blood (pulmonary artery)
      * c’ End pulmonary capillary blood
  + Examples:
    - PaCO2 Partial pressure of CO2 in arterial blood
    - FIO2 Fractional concentration of O2 in the inspired air
* Major functioning of the Lungs: Pulmonary gas exchange—design of gas exchanging system
  + 
    - **External respiration**= gas exchange between the air that we are breathing and the external environment
    - **Internal respiration**= exchange at the tissue levels between the systemic capillaries and the tissues of the body
    - Exchange Cycle
      * When were breathing in air we consider that high oxygen and low CO2. We'll take that gas into the lungs into the conducting airways and also in gas exchanging airways. The oxygen will diffuse into the blood (pulmonary capillary) It will return through the pulmonary veins (4 of these) to the LA through mitral/bicuspid valve into the LV and out through the aorta (high in oxygen and low in CO2--consider this oxygenated/arterial blood). Aorta takes the blood/oxygen to all the various organ systems of the body and when it gets out into those organs the tissues will take up oxygen to carry out metabolism and then they will produce CO2 and H20. CO2 diffuses out of the tissues and into the venous side of the capillaries (this blood is low in O2 and high in CO2-->venous/deoxygenated blood) This blood returns to the R heart through the IVC (lower body) and SVC (upper body)--> RA. Also there is venous blood draining the heart into the RA that drains through the coronary sinus. RA--> tricuspid valve into the RV--> pulmonic valve into the pulmonary artery (contains mixed venous blood; only artery in the body w/ venous blood) and then to the pulmonary capillaries and the high CO2 diffuses out and exhaled into the external environment and more oxygen is taken up in this blood (oxygenated)
* Processes involved in Pulmonary Gas Exchange
  + 
  + When pulmonary gas exchange is optimal, normal Arterial Blood Gases and pH
    - PaO2  100 mm Hg (80-100 mm Hg)
    - PaCO2  40 mm Hg (35-45 mm Hg)
    - pH 7.40 (7.35-7.45)
    - (At sea level, Barometric pressure = 760 mmHg)
* Ventilation (outline of the topics for today!)
  + Volume of gas entering (or leaving) the respiratory tract: Lung Volumes (aka static lung volumes) and Capacities
  + Distribution of that volume in the respiratory tract
  + Composition (partial pressures) of respiratory gases
  + Volume of gas per minute that enters:
    - Conducting Airways = dead space ventilation
    - Gas Exchanging Airways = alveolar ventilation
    - Entire Respiratory Tract = 1 + 2 = total ventilation, aka minute ventilation
* **Volume of gas entering (or leaving) the respiratory tract**
  + Measurement of Lung Volumes and Capacities – Spirometry
    - 
      * There is metal cylinder in a tub of water hooked up to a pulley that you breath in and out of the tube and it causes the cylinder to move up and down (hooked up to a pen)
  + Primary Lung Volumes
    - 🡨know this
    - **Tidal Volume (TV or VT):** Volume of gas inspired or expired with each breath, generally at rest (~500 ml)
    - **Inspiratory Reserve Volume (IRV):** Maximal volume of gas that can be inspired beyond the tidal volume (~2.5 L)
      * Big breathe!
    - **Expiratory Reserve Volume (ERV)**: Volume of gas that can be maximally expired beyond the tidal volume (~1.5 L)
    - **Residual Volume (RV)**: Volume of gas remaining in the lungs at the end of a maximal expiration (~1.5 L)
      * when you exhale you don’t collapse the lungs there is still air in them = the RV
  + **Lung Capacities**
    - **Total Lung Capacity (TLC):** Amount of gas contained in the lungs at the end of a maximal inspiration (~6 L).
      * Total Lung Capacity (TLC) = IRV + TV + ERV + RV = IC + FRC = VC + RV
    - **Inspiratory Capacity (IC):** Maximal volume of gas that can be inspired from the resting expiratory level (~3 L).
      * Inspiratory Capacity (IC) = IRV + TV = TLC - FRC
    - **Functional Residual Capacity (FRC):** Volume of gas remaining in the lungs at the resting expiratory level; i.e., after exhaling the tidal volume (~3 L).
      * Functional Residual Capacity (FRC) = ERV + RV = TLC - IC
    - **Vital Capacity (VC):** Maximal volume of gas that can be expired after a maximal inspiration (~4.5 L).
      * Vital Capacity (VC) = IRV + TV + ERV = IC + ERV = TLC - RV
  + **Importance of the Residual Volume (RV) and Functional Residual Capacity (FRC)**
    - Allow for continuous gas exchange during inspiration and expiration.
      * If alveolus is collapsed no gas exchange can occur so you don't want a collapsed alveolus
    - Prevent wide fluctuations in PAO2 and PACO2 between inspiration and expiration.
    - Prevent lungs from collapsing during expiration, which decreases the work of breathing compared to having to re-inflate collapsed alveoli with each inspiration
      * Think about if you blowing up a balloon it takes a lot of work to initially get it to inflate but once you get past that initial inflation it’s easier to add more air. If you collapsed the lung after each breath it would take a lot of work to keep having to get past that initial inflation
  + **Lung Volumes and Capacities Not Measurable by Spirometry**
    - RESIDUAL VOLUME (RV): Volume of gas remaining in the lungs at the end of a maximal expiration.
      * The residual volume doesn't communicate w/ the spirometer. So the measurements that include the RV cant be measured solely on spirometry.
    - FUNCTIONAL RESIDUAL CAPACITY = ERV + RV
    - TOTAL LUNG CAPACITY = IRV + TV + ERV + RV
  + Methods for Determination of RV, FRC, TLC
    - Gas Dilution Techniques – only measure ventilated lung volume, i.e., gas communicating with the mouth
      * Helium Dilution Technique
      * N2 Washout Technique
    - Body Plethysmography (aka the Body Box)🡨most accurate
      * application of Boyle’s Law (P1V1=P2V2; PV=K)
        + inverse relationship between pressure and volume in a closed system
      * measures total volume of gas in the lungs, including any air that is trapped behind closed airways in diseased lungs, ∴ most accurate
* Distribution of inspired (expired) volume in the respiratory tract
  + Functional Anatomy of the Respiratory Tract
    - 
      * conduction airways are the bronchiole tree (very branchy)
        + Starts with trachea🡪 bronchi🡪 terminal bronchioles
      * Conducting airways lead to the gas-exchanging airways (acinus)
        + Respiratory bronchioles (sometimes this is considered transitional zone)🡪 alveolar ducts🡪 alveolar sacs🡪 alveoli 🡪 gas exchange
  + 
* Composition (partial pressures) of respiratory gases
  + Composition of Dry Inspired Air (@STPD: 0°C, 760 mmHg, 0% H20 vapor)
    - O2 = 20.93% FIO2 = 0.2093
    - CO2 = 0.04% FICO2 = 0.0004
    - N2 = 79% FIN2 = 0.79
  + Partial Pressure of a gas = (%gas/100)(Ptotal) = (Fgas)(Ptotal)
    - In the atmosphere, Ptotal = Barometric Pressure (BP)
      * PIO2 = 0.2093 x 760 mmHg = 159.1 mmHg
      * PICO2 = 0.0004 x 760 mmHg = 0.30 mm Hg
      * PIN2  = 0.79 x 760 mmHg = 600.4 mm Hg
    - At BTPS: 37 °C, 760 mmHg, 100% H2O vapor
      * so to get the partial pressure of a gas in the body compartments we need to subtract the water vapor pressure from the total pressure before we multiply it by the factional concentration of the gas so if we just look at partial pressures and concentrations in the conducting airway we dont have any gas exchange but we do have dry external environment into the body. So now 21% of 760-47 (b/c P water vapor at 37 degrees is a constant and that is equal to 47 mm Hg)
  + **Composition of Humidified Inspired Air in the Conducting Airways (BTPS)**
    - Once you take air in it gets warmed and humidified
      * **O2 = 20.93%** FIO2 = 0.2093 BP= 760 mmHg PH2O = 47 mmHg
      * PIO2 = 0.21 x (P total - P H2O) = 0.21 x 713 mmHg = **149 mmHg**
      * **CO2 = 0.04%** FICO2 = .0004 BP= 760 mmHg PH2O = 47mmHg
      * PICO2 = 0.0004 x (P total - PH2O) = 0.0004 x 713 mmHg = **0.3 mmHg**
      * **N2 = 79%**  FIN2 = 0.79 BP= 760 mmHg PH2O = 47 mmHg
      * PIN2 = 0.79 x (P total - PH2O) = 0.79 x 713 mmHg = **563 mm Hg**
  + **Composition of Air in the Alveoli (BTPS) (Gas Exchanging Airways)**
    - **Now oxygen has been taken up by the pulmonary blood and CO2 has diffused out into the alveoli so ↓ in O2 conc. And ↑ in the CO2 of the alveolus** 
      * **O2 = 14.6%** FIO2 = 0.146 BP= 760 mmHg PH2O = 47 mmHg
      * PAO2 = 0.146 x (P total - P H2O) = 0.146 x 713 mmHg = **104 mmHg**
      * **CO2 = 5.6%** FICO2 = .056 BP= 760 mmHg PH2O = 47mmHg
      * PACO2 = 0.056 x (P total - PH2O) = 0.056 x 713 mmHg = **40 mmHg**
      * **N2 = 79.8%** FIN2 = 0.798 BP= 760 mmHg PH2O = 47 mmHg
      * PAN2 = 0.798 x (P total - PH2O) = 0.798 x 713 mmHg = **569 mm Hg**
  + **Composition of Mixed Expired Air (BTPS)**
    - O2 = 16.8% FIO2 = 0.168 BP= 760 mmHg PH2O = 47 mmHg
    - PEO2 = 0.168 x (P total - P H2O) = 0.168 x 713 mmHg = 120 mmHg
    - CO2 = 3.8% FICO2 = .038 BP= 760 mmHg PH2O = 47mmHg
    - PECO2 = 0.038 x (P total - PH2O) = 0.038 x 713 mmHg = 27 mmHg
    - N2 = 79.4% FIN2 = 0.794 BP= 760 mmHg PH2O = 47 mmHg
    - PEN2 = 0.794 x (P total - PH2O) = 0.794 x 713 mmHg = 566 mm Hg
  + Partial Pressures (mmHg) of Respiratory Gases at Sea Level (BP = 760 mm Hg)
    - 
      * Note I: The partial pressure are given in mm Hg following in parenthesis by the percentage concentration.
      * Note II: H2O vapor is not expressed as a % of the total, because the PH2O is temperature dependent, not concentration dependent. The PH2O at 37°C is 47 mm Hg. This value must be subtracted from the total pressure of 760 mm Hg before multiplying by the fractional concentration of a gas when determining partial pressures of gases anywhere in the body (BTPS); i.e., in tracheal (conducting airways), alveolar, exhaled air, and in arterial and venous blood; only inspired atmospheric air is expressed under STPD.
      * Note III: In arterial and mixed venous blood, the respiratory gases are conventionally expressed in terms of their partial pressure. Therefore, the %’s are not indicated.
* Quantifying the volume of gas per minute that enters: Conducting Airways = dead space (another term for the volume of the conducting airways—not participating in gas exchange) ventilation, Gas Exchanging Airways = alveolar ventilation, Entire Respiratory Tract = total ventilation (1+2)
  + Total Ventilation or Minute Ventilation: Volume of gas per minute that leaves (enters) the entire respiratory tract
    - 
  + Alveolar Ventilation: Volume of gas per minute that leaves (enters) the gas exchanging airways
    - Volume getting to the gas exchanging sit (alveolar volume)
    - 
      * VD is estimated as 1 ml / lb body weight;
      * 150 ml is usually used as a “ball park figure” for the dead space in the conducting airways (anatomical dead space).
  + **Dead Space Ventilation**: Volume of gas per minute that leaves (enters) areas of the respiratory tract that are ventilated but do not participate in gas exchange (e.g., conducting airways = anatomical dead space)
    - 
  + Effect of Δs in VT on VE (dot),VA (dot), and VD (dot)
    - VT (ml) VD (ml) VA (ml) rr VE (L/min) VA (L/min) VD (L/min)
    - 250 150 100 16 4.0 1.6 2.4
    - 500 150 350 16 8.0 5.6 2.4
    - 1000 150 850 16 16.0 13.6 2.4
    - If you have the same rr but cut TV in half then you cut your total ventilation in half
    - VD is constant (it is an anatomical space)
  + Effect of Δs in rr on VE ,VA , and VD
    - rr VT (ml) VD (ml) VA (ml) VE (L/min) VA (L/min) VD (L/min)
    - 8 500 150 350 4.0 2.8 1.2
    - 16 500 150 350 8.0 5.6 2.4
    - 32 500 150 350 16.0 11.2 4.8
  + Effect of Δs in Respiratory Rate and Tidal Volume on Alveolar Ventilation (VA) at Constant Minute Volume (VE)
    - 
  + Lung Volumes and Capacities
  + Functional Anatomy of the Respiratory Tract
  + Composition (partial pressure) of Respiratory Gases
  + Minute Ventilation, Alveolar Ventilation, Dead Space Ventilation
* Assessment of Adequacy of Alveolar Ventilation
  + To Assess the Adequacy of Alveolar Ventilation, Measure PACO2 or PaCO2
    - Alveolar Ventilation Equation
      * Normal Alveolar Ventilation = Normal PaCO2 = 35-45 mmHg
      * ↑ Alveolar Ventilation = Hyperventilation = PaCO2 < 35 mmHg
      * ↓ Alveolar Ventilation = Hypoventilation = PaCO2 > 45 mmHg
* Effects of Changes in Alveolar Ventilation on Gas Exchange (i.e., PAO2 and PACO2)
  + How do changes in alveolar ventilation affect PAO2?
    - Normal Alveolar Ventilation on Room Air (21% O2)
      * PACO2 ≅ 40 mmHg
      * PAO2 ≅ 100 mmHg
    - PAO2 is calculated using the Alveolar Air Equation:
      * + VCO2/VO2  (= Respiratory Exchange Ratio, R)
    - PAO2 = [FIO2 (BP – PH20)] – (PaCO2/R)

= [0.21 (760 - 47)] – ( 40/0.8)

= 150 – 50

= 100 mmHg

* + Double Alveolar Ventilation → One-half PACO2 (40 → 20 mmHg)
    - Alveolar Ventilation Equation
      * PACO2 or PaCO2 = CO2 Production (VCO2)/Alveolar Ventilation (VA)
    - Double Alveolar Ventilation (while breathing Room Air)
      * ↑PAO2 from 100 → 125 mmHg
    - Alveolar Air Equation
      * PAO2 = PIO2 – PACO2 / R

PAO2 = [FIO2 (BP – PH20)] – (PACO2/R)

= [ 0.21 (760-47)] – (20/0.8)

= 150 – (20 x 1.25)

= 150 – 25

= 125 mmHg

* + Halve Alveolar Ventilation → Double PACO2 (40 → 80 mmHg)
    - Alveolar Ventilation Equation
      * PACO2 or PaCO2 = CO2 Production (VCO2)/Alveolar Ventilation (VA)
    - Halve Alveolar Ventilation (while breathing Room Air)
      * Cut PAO2 in half (100 → 50 mmHg)
    - Alveolar Air Equation
      * PAO2 = PIO2 – PACO2 / R

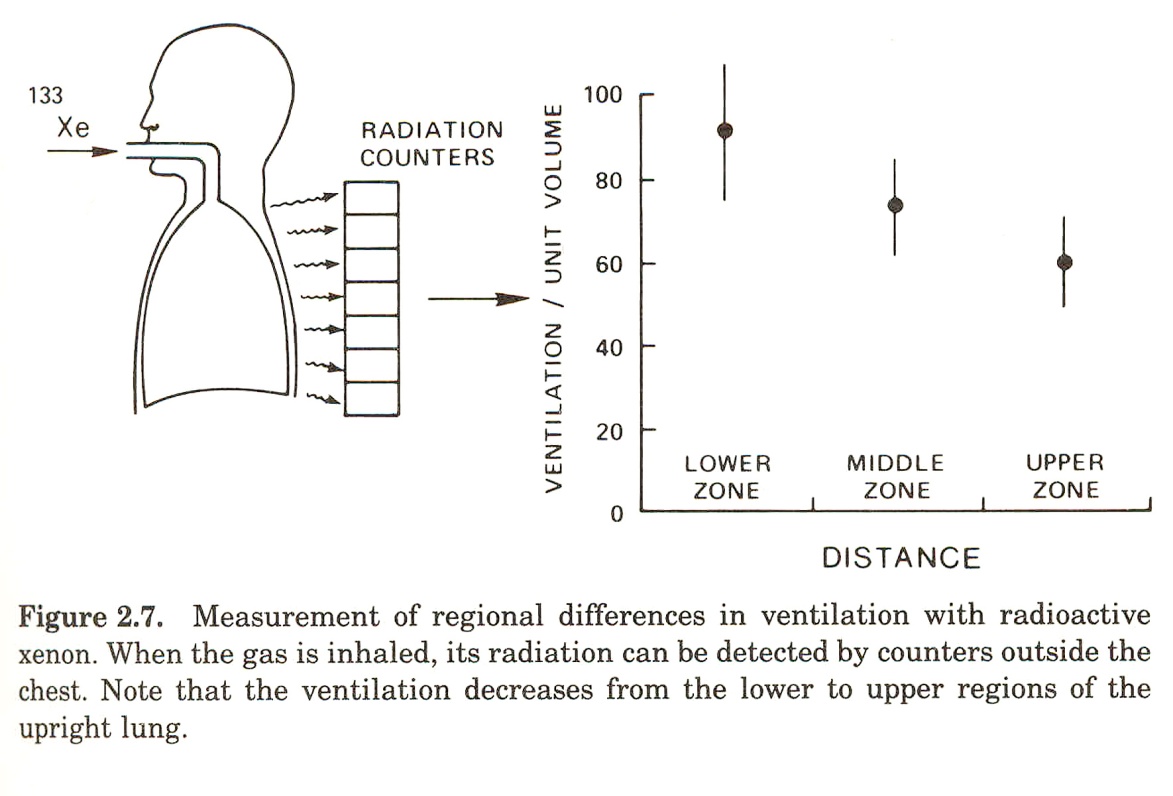
PAO2 = [FIO2 (BP – PH20)] – (PACO2/R)

= [ 0.21 (760-47)] – ( 80/0.8)

= 150 – (80 x 1.25)

= 150 – 100

= 50 mmHg

* Summary: Relationship Between Alveolar Ventilation, PACO2, and PAO2
  + Normal Alveolar Ventilation = Normal PACO2 = 40 mmHg and Normal PAO2 = 100 mmHg
  + Hyperventilation: PAO2 increases 1.25 mmHg for every mmHg decrease in PACO2
  + Hypoventilation: PAO2 decreases 1.25 mmHg for every mmHg increase in PACO2
  + Clinically, ok to round,
    - Hyperventilation: PAO2 increases 1 mmHg for every mmHg decrease in PACO2
    - Hypoventilation: PAO2 decreases 1 mmHg for every mmHg increase in PACO2
* Regional Distribution of Ventilation in the Upright Lung
  + 
    - APEX (non-dependent regions)
      * ↓ Hydrostatic Pressure
      * ↓ Ventilation per Unit Volume
    - BASE (gravity dependent regions)
      * ↑ Hydrostatic Pressure
      * ↑ Ventilation per unit volume
* Formative Questions
  + The volume of gas present in the lungs following a maximal inspiration is the:
    1. Inspiratory reserve volume
    2. Inspiratory capacity
    3. Vital capacity
    4. Total lung capacity
    5. Functional residual capacity
  + The volume of gas remaining in the lungs after a maximal expiration is the:
    1. Residual volume
    2. Expiratory reserve volume
    3. Expiratory capacity
    4. Reserve capacity
    5. Functional residual capacity
  + Which of the following is arranged in order from the area of highest to lowest PO2?
    1. Humidified inspired air - dry inspired air - alveolar air - expired air
    2. Inspired air - expired air - alveolar air - arterial blood
    3. Alveolar air - arterial blood - expired air - mixed venous blood
    4. Arterial blood - expired air - dead space gas -mixed venous blood
  + If a subject at rest voluntarily doubles her respiratory rate while maintaining the same tidal volume, which of the following would be unchanged?
    1. Minute ventilation
    2. Alveolar ventilation
    3. Dead space ventilation
    4. Dead space volume
    5. PaCO2
  + A first-year medical student reports for his first examination. As the chief proctor approaches, he remembers he has his cell phone in his pocket. He starts hyperventilating and doubles his alveolar ventilation. What would happen to his PaCO2?
    1. no change
    2. doubled
    3. halved
    4. decreased by 24
    5. increased by 24